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Statistical Relationships Between Geotechnical Properties of Gulf of Mexico Sediments

By

William R. Bryant and Peter K. Trabant, Texas A&M U.

ABSTRACT

The design of adequate foundations for offshore installations, of all natures, requires a knowledge of the engineering properties of the sediments from the first dozen meters below the ocean floor.

This study presents the profiles of shear strength, water content and bulk (wet) density to a depth of 12 meters for eighty cores retrieved from all provinces of the Gulf of Mexico.

Equations of the linear relationships for all data as well as for each physiographic area within the Gulf are presented in order to assist the engineer towards the reliable solution of his problems within the deeper portion of the Gulf of Mexico.

INTRODUCTION

As part of a continuing program of investigation of the geotechnical properties of marine sediments within the Gulf of Mexico, several hundred cores have been collected from all provinces of the basin over the past seven years. Eighty of these cores were analyzed for shear strength and other mass physical properties throughout their lengths. The object of this paper is to present the results in a statistical form to demonstrate correlations and empirical relationships between certain properties with depth for selected provinces of the Gulf of Mexico. These data may be used as an aid in foundation analyses for the determination of bearing capacities of ocean bottom sediments as required for the rational design of offshore engineering structures to be placed in the deeper portions of the Gulf of Mexico. The data also affords a comparison with similar investigations conducted in other areas, such as those by Holmes and Goodell (1964), Hironaka (1966) and Simpson and Inderbitzen (1971).

The latter investigations encompassed relatively small areas and were limited to coring depths of less than two meters. All three employed multiple linear regressions in an attempt to explain the variation of an independent variable (usually shear strength) with respect to other parameters such as depth in core, water content, clay

References and illustrations at end of paper.

CONTRIBUTION #491

percentage, Atterberg limits, and, carbonate content. In all cases it appears that at least fifty percent of the variability of shear strength can be attributed to either the depth in core or water content and that an increase in the number of variables accounts for only a small additional percentage of the variability. A discussion of the aerial distribution of the data presented herein has been given by Bryant and Delflache (1971) including compression indices for a number of consolidation tests on samples from the Gulf of Mexico. Bryant and Wallin (1968) carried out a rather extensive study on the stability and geotechnical characteristics of marine sediments from the Gulf of Mexico, concluding that to a depth of 30 meters below the sediment-water interface most sediments in the Gulf are stable in their present environment. An empirical relationship of expected minimum shear strength with depth was also presented.

GEOLOGICAL SETTING

Ewing and others (1968) have presented a detailed description of the geology and structure of the Gulf of Mexico. Figure 1 is a map of the bathymetry and major physiographic provinces of the Gulf of Mexico which has been further subdivided into major sedimentary areas. The areas are based upon differences in sediment texture and composition as follows: Area I encompasses the extensive Texas-Louisiana shelf area and adjacent continental slope, including the diapiric structures of the "humocky zone". The sediments in this area are mostly terrigenous light brown to blue, fossiliferous, silty lutites. Area II is dominated by a large submarine fan of sediments derived from the Mississippi River. These sediments consist primarily of terrigenous turbidite sequences of silts and clays which originated at the apex of the fan. Area III consists of the Sigsbee Abyssal Plain, an extremely flat region produced by turbidite flows from the Mississippi fan and peripheral slopes. The plain contains a small cluster of topographical prominences known as the Sigsbee Knolls in the southwestern portion. The sediments on the knolls lack significant turbidite sequences due to their elevation above the plain. The sediments of the abyssal plain are primarily terrigenous silts and clays covered with a recent blanket of pelagic ooze. Samples of carbonate turbidites, originating from the Campeche bank to the south, are excluded from the data of this area. Area IV includes the West Florida Shelf and scarp, a carbonate platform covered with only a very thin veneer of recent terrigenous, pelagic and carbonate sediments. Area V consists of the Campeche Bank and is similar in many aspects to Area IV. It includes carbonate material which has accumulated at the base of the Campeche Scarp as well as within the Campeche Canyon. Area VI contains the complex folds of the Mexican ridge system described by Bryant et al. (1968) and the Mexican continental shelf. Landward of the ridge folds, sediments are terrigenous in origin while the portion seaward and extending down to the Abyssal plain consists of predominantly pelagic sediments.

SHEAR STRENGTH

Shear strength of the sediment was determined on board ship immediately upon retrieval of the core by use of a standard vane shear apparatus. A four-bladed vane, $\frac{1}{2}$-inch long and $\frac{1}{2}$-inch wide, was buried to a depth of one inch below the sectioned surface of the sediment core. Shear strength is expressed as:

$$s = c + \bar{\sigma} \tan \phi$$

where c is the cohesion, $\bar{\sigma}$ is the effective normal pressure and ϕ is the angle of internal friction. The effective normal pressure $\bar{\sigma}$ is equal to the normal load σ minus the pore water pressure u:

$$\bar{\sigma} = \sigma - u$$

The speed at which the sediment was sheared (40 to 60 degrees per minute) was sufficiently fast to consider that the sediments were sheared in an unconsolidated-undrained state. In the undrained unconsolidated condition $u = \sigma$ and therefore $s = c$. Thus, measured vane shear strength is actually equal to the cohesion of the sediments.

Figure 2 is a plot of shear strength (cohesion) versus depth in core for 1480 samples, analyzed to a maximum depth below the sediment-water interface of 12 meters. A linear regression employing the least squares fit for all points shows a positive relationship between shear strength and depth. A nonlinear analysis (6th order) was also practically linear for this data. Sorting of the data according to the areas in Fig. 1 produced the linear regression lines shown in Fig. 3. It is apparent that the variation of the profiles for the different areas is of the order of less than 50 gm/cm^2 (100 PSF) except for Area IV. In Area IV the number of samples was limited to 87 and the sediments were highly calcareous and overconsolidated. The resulting empirical equations for all the data, as well as each area, are presented in Table I.

WATER CONTENT

Upon completion of the vane shear test a sample of the material is removed and sealed for later determination of water content, bulk (wet) density, void ratio, specific gravity of solids, size analysis and carbonate content.

The water content is the ratio of the weight of water to weight of solids expressed as a percent, and is simply obtained by weighing a sample in its natural wet state and then again upon drying at 105°C for 24 hours. A plot of water content versus depth in core for the 1480 samples is presented in Fig. 4. The straight line in the figure is a linear regression fit (least squares method) drawn through the plot. A negative linear relation is evident with depth in core and is expected as a result of the consolidation of the sediments under increasing overburden pressures. In the process of consolidation the sediments are subjected to a net reduction in void ratio, or water content in our case where the sediments are assumed to be fully saturated, with increasing overburden which is equivalent to depth of burial.

A plot of the regression lines for the different areas in Fig. 5 display similarities, with minor variations due mostly to the reduced number of samples at depths in core over 500 cm for several areas. The equations of the linear regression analyses are presented in Table I.

A plot of the log of shear strength versus water content is presented in Fig. 6. Differences of an order of magnitude of the shear strength for a given water content are apparent in the scatter diagram. This results in a very poor correlation coefficient for this fit. It may be possible, however, to obtain a better relationship by eliminating other variables or by grouping the samples which have similar sand and clay percentages, as well as carbonate content. Figure 7 is a plot of water content against bulk density (wet unit weight) and demonstrates the inverse hyperbolic relationship between the two parameters. This results from the fact that bulk density is a function of water content, void ratio and specific gravity. Void ratio (e), which is the ratio of the volume of voids to the volume of solids, is directly related to water content, thus the only variations are due to differences in the specific gravity of the solid portion of the sediment.

A plot of the values obtained from the tables published by Bennett and Lambert (1971) correctly match the data presented in Fig. 7 for a specific gravity of 2.68 gm/cc, which is the average value for the data analyzed herein.

Those points which fall out of the range of the linear cluster must be explained by errors in procedures or computations and are easily recognized for rectification or elimination.

BULK DENSITY

Figure 8 represents a plot of bulk density versus depth with the regression line of least squares fit. In spite of the scatter, better than seventy percent confidence is provided for a variation of two tenths of the bulk density. The relationship of the linear regressions for all six areas to that of all the combined data is very close (Fig. 9). A plot of bulk density versus void ratio (e) (Fig. 10) shows a similar relation as ascribed to bulk density and water content (Fig. 7). This is to be expected as the sediments are fully saturated. Thus the void ratio (e) is related to water content (w) by $e = Gw$. The difference between the two parameters is controlled by the variation in the specific gravity (G) of the solids.

CONCLUSIONS

Statistical relations between shear strength, water content and bulk density with depth below the sediment-water interface have provided empirical equations for the respective profiles of these properties within the Gulf of Mexico. Differences in the above relations between the various physiographic provinces are minor. The relationship between shear strength and depth is quite different from that obtained by Simpson and Inderbitzen (1971) in a small gullied area off Southern California. But this is to be expected because of the difference in sediment types between the two areas and the limited depth sampled, 130 cm compared to over 10 meters in the present study.

A relationship between water content and the log of shear strength does not appear useful in its present form while those between bulk density, water content and void ratio provide practical curves within the limits discussed. Thus it is apparent that useful linear relations of certain mass physical properties exist over a large area, in spite of a wide variety of depositional environments, sediment textures and mineralogy.

ACKNOWLEDGMENTS

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TABLE I - PREDICTING EQUATIONS FOR SHEAR STRENGTH, WATER CONTENT AND BULK DENSITY WITH DEPTH FOR SEDIMENTS FROM THE GULF OF MEXICO

For all data n = 1480	S = 82+(.2)D	W = 113.8-(.045)D	BD = 1.44+(.00015)D
Area I n = 264	S = 133+(.14)D	W = 97.0-(.037)D	BD = 1.52+(.00011)D
Area II n = 516	S = 65+(.2)D	W = 120.3-(.055)D	BD = 1.41+(.00018)D
Area III n = 343	S = 41+(.26)D	W = 121.4-(.050)D	BD = 1.40+(.00018)D
Area IV n = 87	S = 99+(.5)D	W = 128.1-(0.29)D	BD = 1.38+(.00008)D
Area V n = 112	S = 156+(.18)D	W = 104.4-(.009)D	BD = 1.45+(.00002)D
Area VI n = 151	S = 148+(.21)D	W = 10[illegible].7-(.0[illegible])D	BD = 1.48+(.0001)D

S = Shear strength in PSF
D = Depth below mudline in cm
W = Water content (% dry weight)
BD - Bulk density (gm/cc)

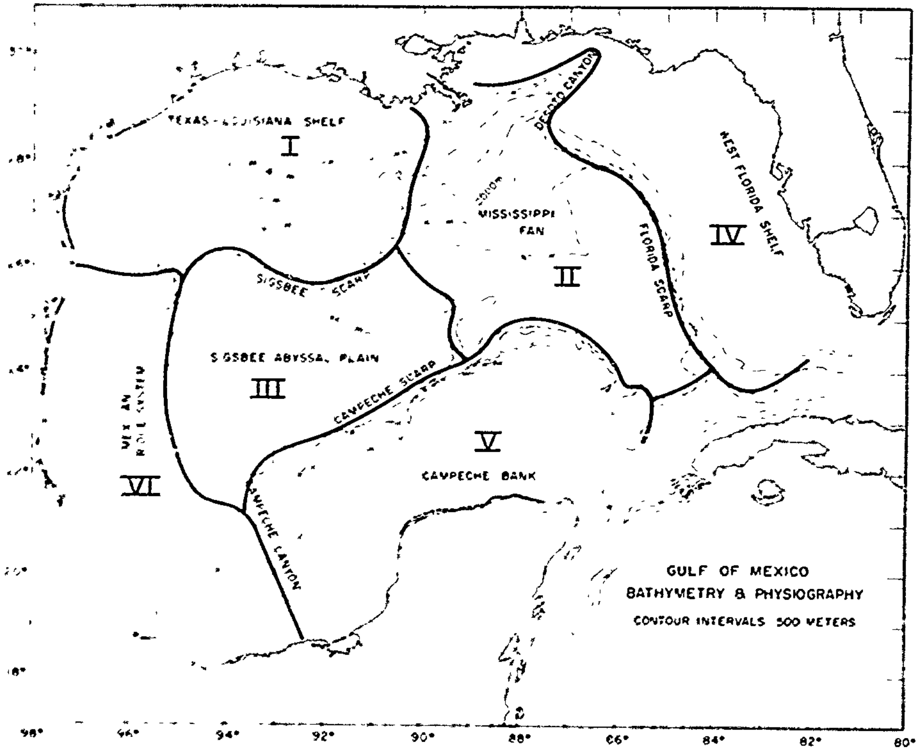

Fig. 1 - Bathymetric chart of the Gulf of Mexico with physiographic areas.

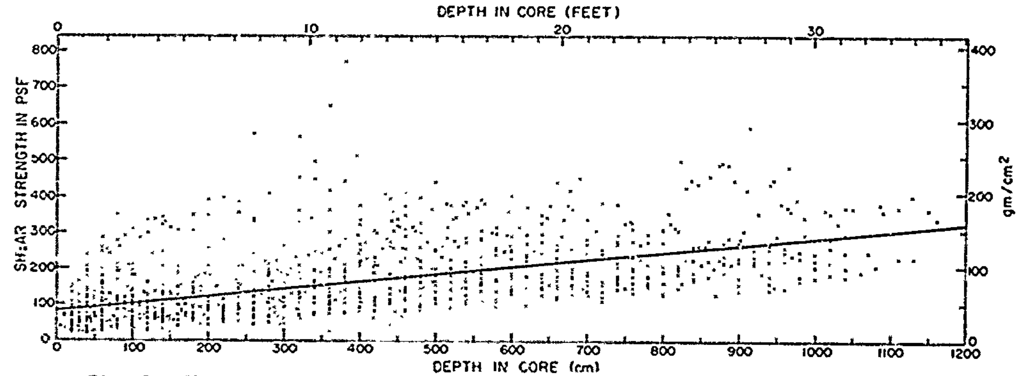

Fig. 2 - Shear strength vs depth below sediment-water interface for combined data from all areas.

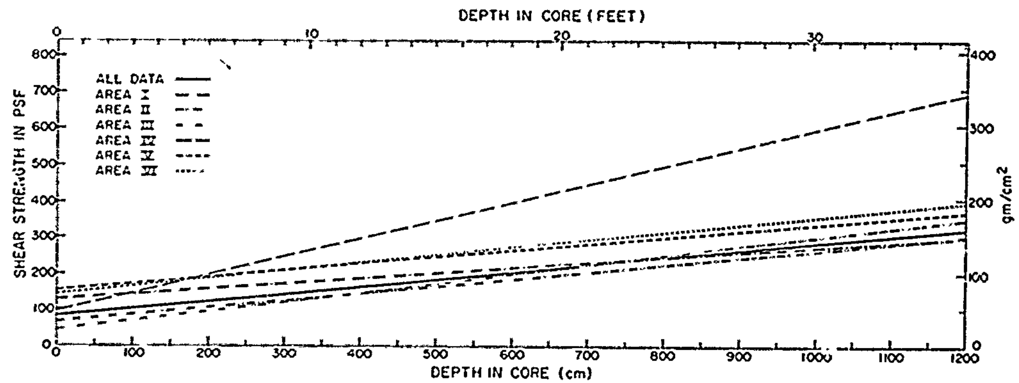

Fig. 3 - Shear strength vs depth below sediment-water interface for different physiographic areas.

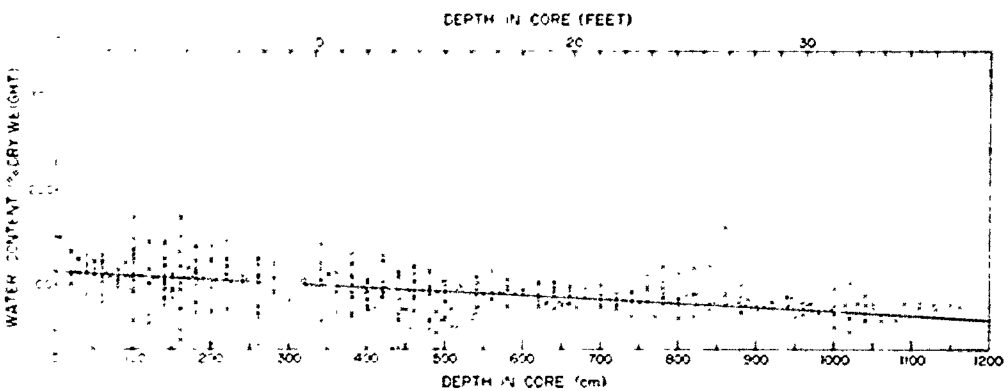

Fig. 4 - Water content vs depth below sediment-water interface for combined data from all areas.

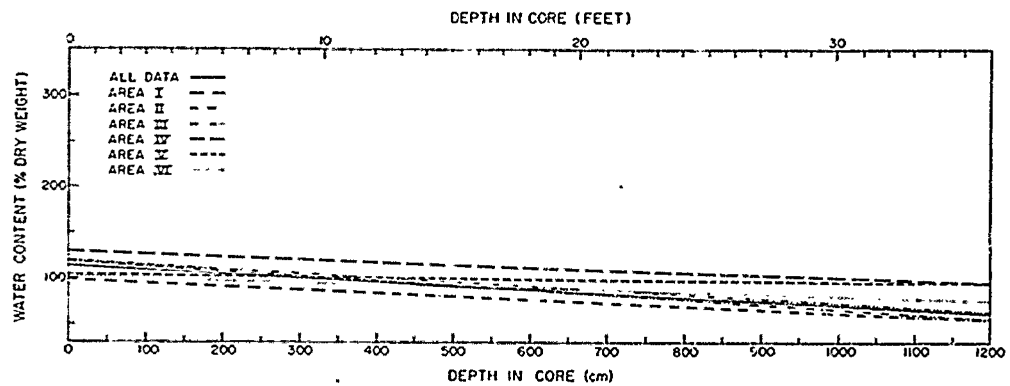

Fig. 5 - Water content vs depth below sediment-water interface for different physiographic areas.

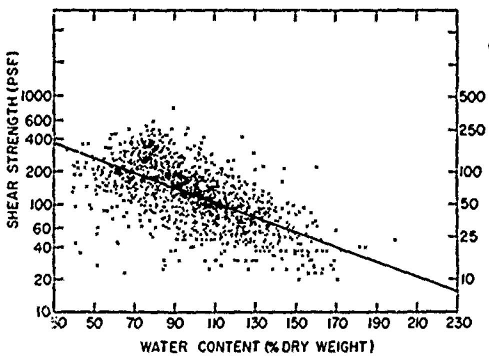

Fig. 6 - Log shear strength vs water content for combined data from all areas.

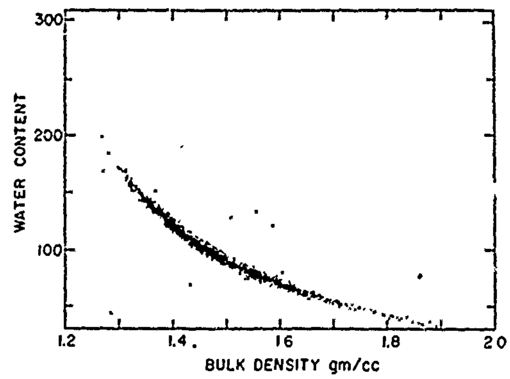

Fig. 7 - Water content vs bulk density (unit wet weight) for combined data from all areas.

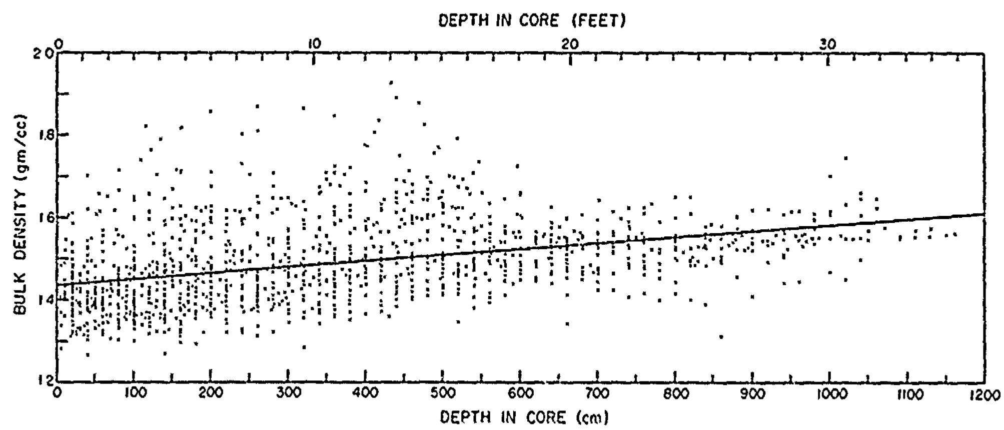

Fig. 8 - Bulk density vs depth below sediment-water interface for combined data from all areas.

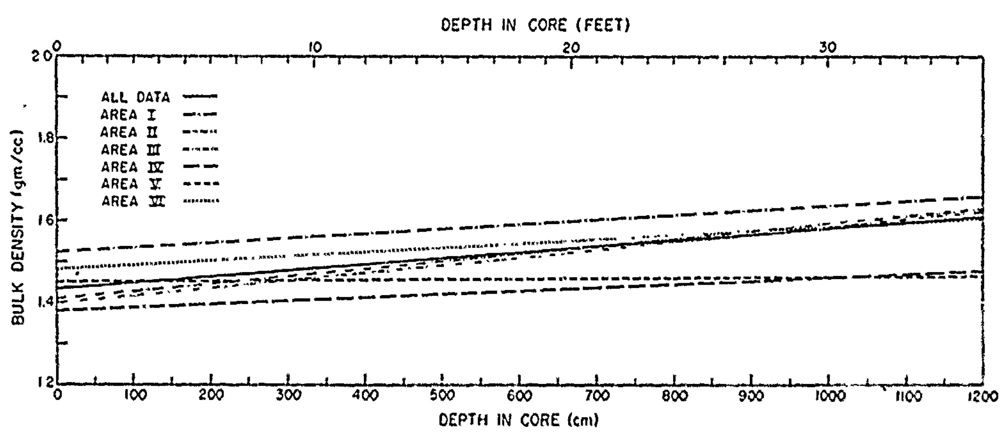

Fig. 9 - Bulk density vs depth below sediment-water interface for different physiographic areas.

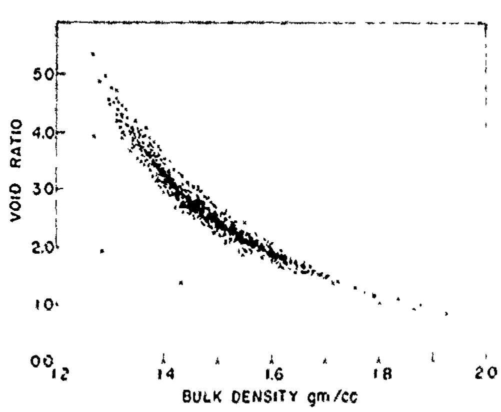

Fig. 10 - Bulk density vs void ratio for all data.